Urban Heat Island Resilience in Athens: Analysing the Effectiveness of Green Roofs for Current and Future Climates

ABSTRACT: Athens, Greece, has a Mediterranean climate, characterized by very hot summers and cool winters that present microclimate challenges both indoors and outdoors. The city's concrete construction exacerbates the situation, making it difficult to maintain a comfortable temperature. Green roofs could be one possible solution, but it is uncertain if they are a reliable and effective strategy to positively affect the city's microclimate. Climate change is also a growing concern in Athens, and its impact on the city's infrastructure has become a significant challenge. Maintenance of homes and roads has also been problematic. The city's Mediterranean climate, combined with inadequate preparation for extreme weather, has resulted in unforeseen fires and unusual snowfall. To improve Athens' future, adapting to these changes is essential. One proposed solution is to transform certain city areas with green roofs. However, it is necessary to assess whether this approach is effective in improving the microclimate. This study used the ENVI-met software to explore the potential benefits of adding green roofs in mitigating the urban heat island effect and enhancing overall thermal comfort and well-being. The results were encouraging, suggesting that green roofs could be an effective solution for microclimate adaptation in Athens.
KEYWORDS: Climate change, green roofs, Microclimate, Urban Heat Island.

1. INTRODUCTION

Cities are dealing with a range of issues because of increased urbanisation and climate change, including urban heat island (UHI) effects, reduced air quality, declining biodiversity, and a lack of green space. Green roofs are one possible option to counter these problems, converting rooftops into dynamic and sustainable urban environments and generating pockets of cooler, very localised microclimates [1-5]. This research examined, through simulations using the microclimate simulation software ENVI-met, the possible benefits of green roofs as a sustainable urban solution to a neighbourhood in Athens, Greece. Global temperature increases disproportionately influence metropolitan areas via the urban heat island effect. Athens is a city that already experiences hot summers and faces various issues because it has not developed and adapted to the environmental challenges posed by a warming climate. This study has explored the hypothesis that implementing green roofs could reduce the impact of the urban heat island by cooling outdoor air temperatures. By simulating the effects of green roofs in the current climate and projecting their impact into the years 2050 and 2080, the effectiveness of these solutions in mitigating the effects of climate change on the city and improving the well-being of its residents can be evaluated. Greece faces economic challenges, necessitating a pragmatic approach to climate adaptation. It is necessary to reconcile the need for climate adaptation with the constraints of Greece's economic landscape. Through diligent research, innovative solutions, and simulation-based assessments, a sustainable approach can be found to foster a better future for Athens and its inhabitants.

2. METHODOLOGY

This research used the commercial software ENVI-met (https://www.envi-met.com/), which is a high-resolution microclimate modelling system capable of simulating interactions between surfaces, vegetation, and air in urban environments with a typical resolution down to 0.5m in space and 1- 5 sec in time. 3D models of buildings and neighbourhoods can be created, and weather data can be imported for current and future climates. This study obtained current, 2050 and 2080 weather data for Athens from the climate generation software Meteonorm (https://meteonorm.com/en/). An analysis of Athens took a historical overview of how the modern city was created (materials used and identified heights). It was decided to work in the Pireaus area in Eleftheriou Venizelou for this study, which focused on the use of green roofs for microclimate mitigation in this district. In this study, the contemporary climate was analysed by the data of temperatures, wind speeds and directions, solar radiation and the sky cover range.

Once the district had been identified, using Google Maps enabled the areas of individual roofs to be estimated, while the heights of the green roof plants were based on previous similar studies. For the analysis of the microclimate in general, current, 2050 and 2080 weather data for Athens were obtained from the climate generation software Meteonorm. Finally, a digital twin of the district was developed in ENVI-met v5.1.1.

3. CLIMATE CONTEXT

Athens has a Mediterranean climate with hot, dry summers and mild, wet winters. The city's location on the eastern shore of the Mediterranean influences the climate, resulting in hot, dry winds blowing in from North Africa during the summer months.

The spring months in Athens (March-May) are characterized by hotter temperatures than the colder winter months, with average air temperatures between 15 and 18°C. Although precipitation is common at this time of year, it tends to be lighter and less frequent than in winter. The summer months (June - August) can be very hot in Athens, with average monthly summer temperatures ranging from 29°C to 32°C. The city is also dry at this time of year, with very little rainfall. Note that temperatures can rise significantly during a heat wave and exceed 38°C on some days. Autumn in Athens (September - November) is characterized by mild temperatures and lower humidity. September average highs are around 29°C but as the season progresses temperatures start to drop, with average highs around 15°C in November. Precipitation increases again at this time of year but remains relatively low compared to the winter months. Figure 1 shows how monthly average air temperatures in Athens are predicted to change in 2050 and 2080 compared to current conditions by 2 to 3°C in 2050 and by 3 to 4°C in 2080.

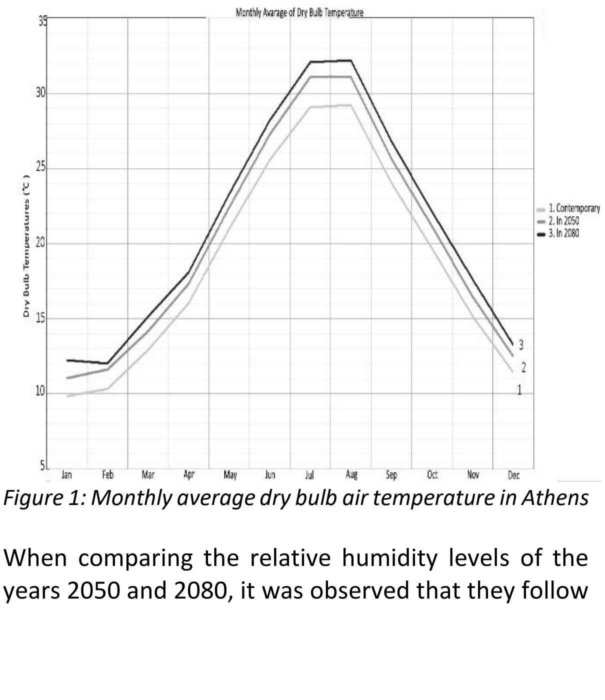

Figure 1: Monthly average dry bulb air temperature in Athens

When comparing the relative humidity levels of the years 2050 and 2080, it was observed that they follow similar patterns throughout most months. However, there is a noticeable change in February 2080, where the humidity levels increase. In contrast, the winter months of 2050 show a slight increase, but there is a significant decrease in the summer months. The humidity levels in 2050 are 2% lower than those in 2080 during the summer months. Nevertheless, the humidity levels for both years never go below 42% or exceed 71% (Figure 2).

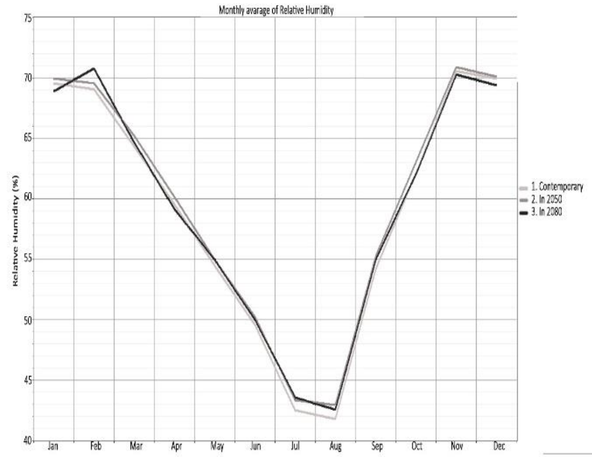

Figure 2: Monthly average of relative humidity in Athens

Figure 3 shows that there is a range of values related to wind speed. The changes in wind speed for the years 2050 and 2080 are concentrated in different months. Overall, there are no noticeable changes between contemporary wind speeds and 2050. At the same time, the comparison (Figure 3) shows an increase of approximately 0.1 m/s in February, a decrease of approximately 0.08 m/s in March, and a decrease of 0.1 m/s in June. This analysis reveals that the most notable changes are occurring between February and March, and June and July. However, all three graphs exhibit similar behaviour, with the year 2080 showing the most significant changes.

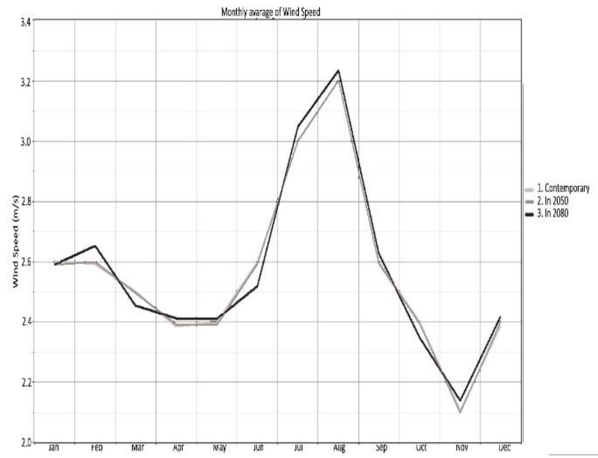

Figure 3: Monthly average wind speed in Athens

2.1 Simulation by ENVI-met.

A 3D recreation of the Piraeus Venizelou area of Athens, located near the coast and mountains, was generated through ENVI-met (Figures 4 and 5) and microclimate conditions were simulated without and with green roofs added to all flat roofs in the area. Analysis was undertaken using current, 2050 and 2080 climate data. The study focussed on the 15th July since, according to the data, this would be the hottest day.

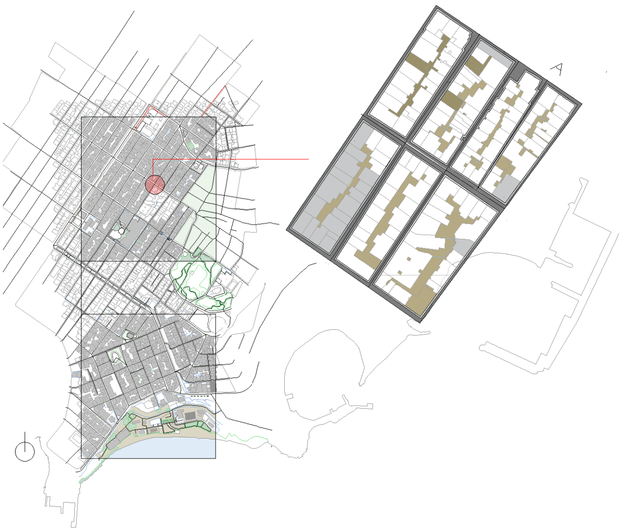

Figure 4: Pireaus Venizelou area of Athens, Greece

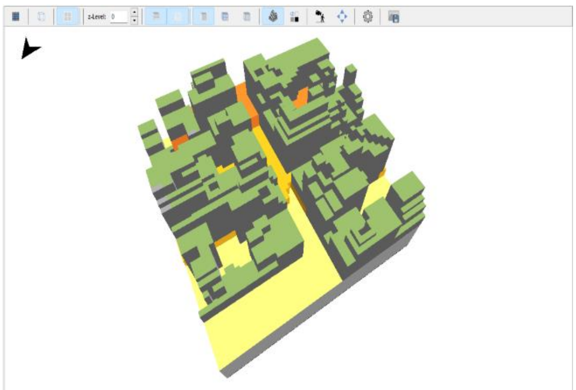

Figure 5: 3D model of the location in ENVI-met

3. DISCUSSION AND RESULTS

Based on the results obtained from ENVI-met (shown in Figure 6 Figure 7, Figure 8 and Table 1), the use of green roofs had a positive impact on the microclimate. By analysing the changes in the current weather, it can be inferred that the hourly temperature reduction was 1.5°C. Furthermore, the data for 2050 suggest that this reduction will be maintained. On the other hand, for current climatic conditions with a green roof, the wind speed and relative humidity increased by 0.36m/s and 2% respectively. However, in the year 2050, this increase was predicted to be 0.76m/s and 7%. In 2080 the data showed a clear rise in temperatures, with an increase of 3.3°C compared to 2005 and a projected increase of 2.7°C by 2050 with the implementation of green roofs. At the same time, there has been a decrease in relative humidity, with a reduction of 1% compared to current data, but with a significant increase of 5% anticipated by 2050.

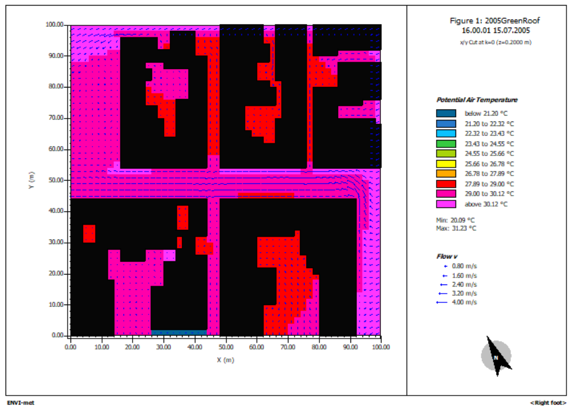

Figure 6: Simulation of contemporary climate ENVI-met

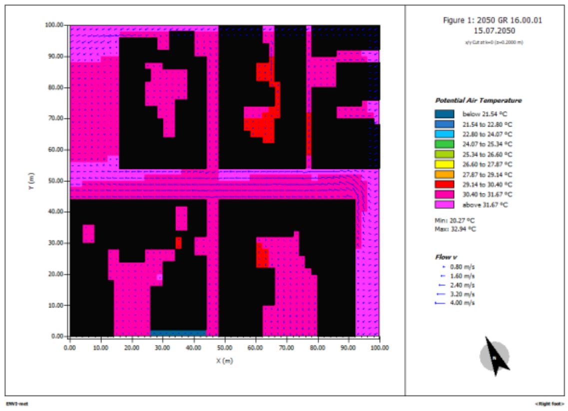

Figure 7: Simulation of 2050 climate ENVI-met

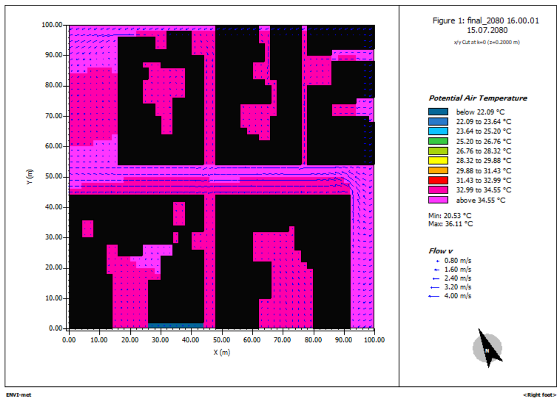

Figure 8: Simulation of 2080 climate ENVI-met

Considering the impact of structures, placement, and orientation on green roofs, the green roof placement must be studied carefully. The absorption of heat, the increase in wind speed and relative humidity has physical relationships with the building structure in which it is located, regardless of the location. It is important to consider the significant impact and the need for different adaptations as climate changes over the years, especially if green roofs become widely adopted.

Table 1: Average hourly results with and without green roofs.

Time	AT(°C)	RH(%)	WS(m/s)
July current without green roofs			
15:00	29.4	32	0.51
16:00	29.4	32	0.51
July current with green roofs			
15:00	27.9	34	0.87
16:00	27.9	34	0.85
July 2050 with green roofs			
15:00	28.5	39	1.27
16:00	28.6	39	1.25
July 2080 with green roofs			
15:00	31.2	39	1.29
16:00	31.7	37	1.27

AT: Air Temperature; RH Relative Humidity; WS: Wind speed

3.1 Comparison of contemporary, 2050 and 2080 with green roof.

In order to obtain a deeper analysis of the results, changes in temperature, relative humidity, and wind speed were studied in different years. It is crucial to understand how climate change affects the solution since cities act as structures that both absorb and emit heat. Therefore, it is essential to study the changes and behaviour of these structures with natural materials such as green roofs. The results of this study are as follows:

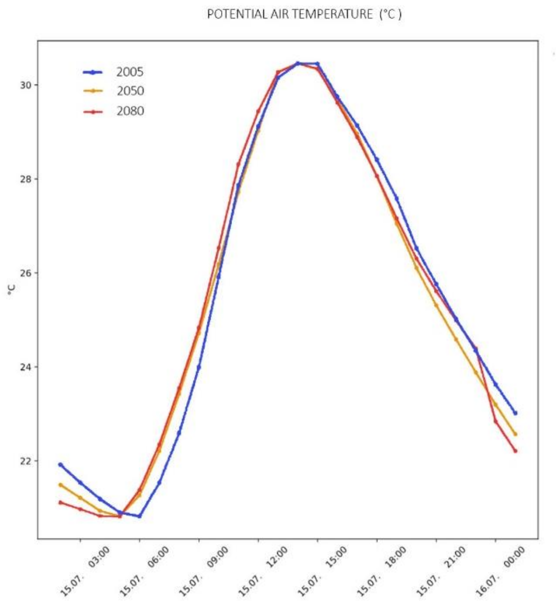

Figure 9: Comparison of Potential air temperature between contemporary climate, 2050 and 2080 with green roof

Figure 9 clearly illustrates the difference between the years. July 15th was chosen to observe changes in temperature between current, 2050 and 2080 data. The highest temperature was recorded in the year 2080, at 20°C, while 2050 recorded a temperature of 21°C and current temperature was 22°C. The difference in temperature during the day is positive. Initially, it was expected that the year 2080 would exceed the temperature by 4°C, but the application of a green roof has improved it by 1 to 2°C. There are no significant changes in temperature in the year 2050, and the temperature drops by one degree after 4 p.m. The temperature is much lower in 2080 during daylight hours.

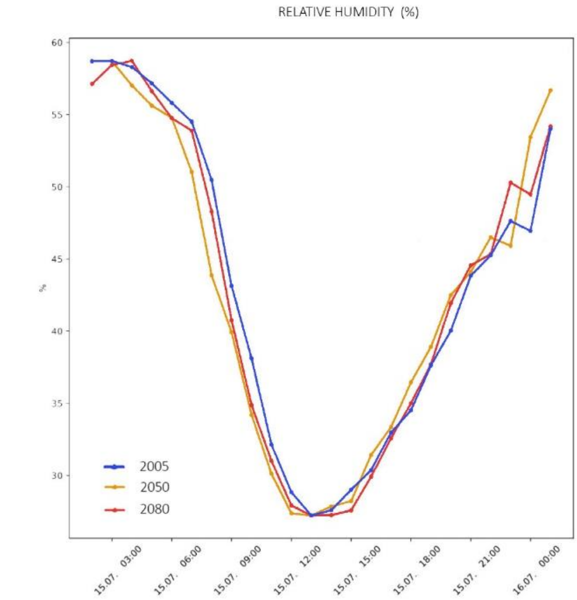

Figure 10: Comparison of relative humidity between contemporary climate, 2050 and 2080 with green roof

Figure 10 displays how relative humidity levels change when a green roof is implemented in the years 2050 and 2080, as compared to current data. Overall, relative humidity will decrease more in 2050 compared to 2080 and current when it arrives at 58%. Initially, there is a 3% decrease in 2050 and a 2% decrease in 2080. Throughout the day, the decrease in relative humidity is 3% and 2% for 2050 and 2080, respectively. There are some specific changes throughout the day, such as no difference at 12:00 am and higher levels in 2050 during the hours of 3:00 p.m. being this lower than 30%. to 9:00 p.m. In contrast, 2080 is only 1% higher during those same hours. During the night, relative humidity levels are lower in both 2050 and 2080, with 2050 being higher.

Based on Figure 11, there is a decrease in wind speed during the early morning hours and a noticeable increase during the daytime hours until nighttime, which is the same as the years 2005 and 2080.

It is worth noting that the wind speed during the afternoon hours, which are the hottest, has the most significant increase. In 2050, the wind speed will increase by 0.05 m/s, while in 2080 it will increase by 0.1 m/s compared to current data. At 3:00 p.m. in 2080, the wind speed reached 2 m/s.

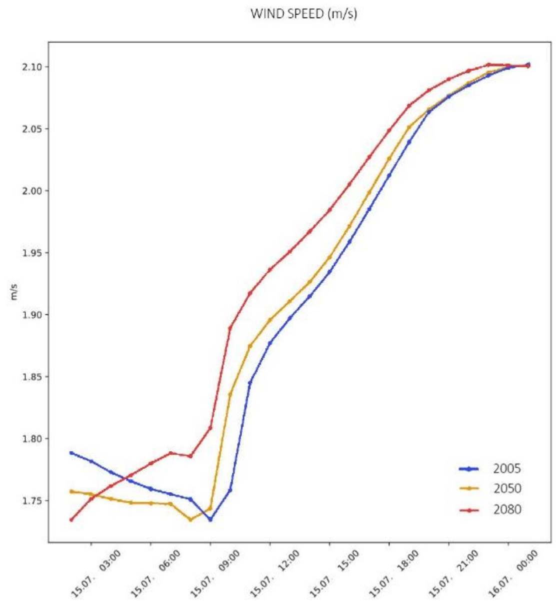

Figure 11: Comparison of Wind speed between contemporary climate, 2050 and 2080 with green roof

After conducting an analysis, it was observed that the green roof affected the relative humidity (RH) in comparison to the reference roof. On average, the RH on the green roof was higher due to its soil composition, which absorbs more rainwater and water during rainfall or irrigation. This feature promotes more evapotranspiration of water from green roofs, increasing relative humidity in the surrounding air. The benefits of increased relative humidity levels are numerous, including reducing the risk of respiratory infections, reducing static electricity, and preventing wooden furniture from splitting. It can also aid in the prevention of airborne viruses and bacteria, which thrive in dry air. Moreover, increased relative humidity levels can make the air feel warmer, reducing the need for heating during colder months and, in turn, lowering energy expenses.

3.2 Physiological Equivalent Temperature (PET)

The Physiological Equivalent Temperature (PET) is defined as the air temperature at which, in a typical indoor setting (without wind and solar radiation), the heat budget of the human body is balanced with the same core and skin temperature as under the complex outdoor conditions to be assessed [6]. Upon analysing the findings of the Physiological Equivalent Temperature (PET) and evaluating the current, 2050, and 2080 climate conditions, a disconcerting pattern becomes evident. Specifically, there was observed to be a rise in temperature during the day and an increase in heat spreading throughout the city, which can be attributed to the greenhouse effect. Figure 12 provides further evidence of this phenomenon, clearly illustrating the temperature increase during the day and heat spread throughout the city. Given

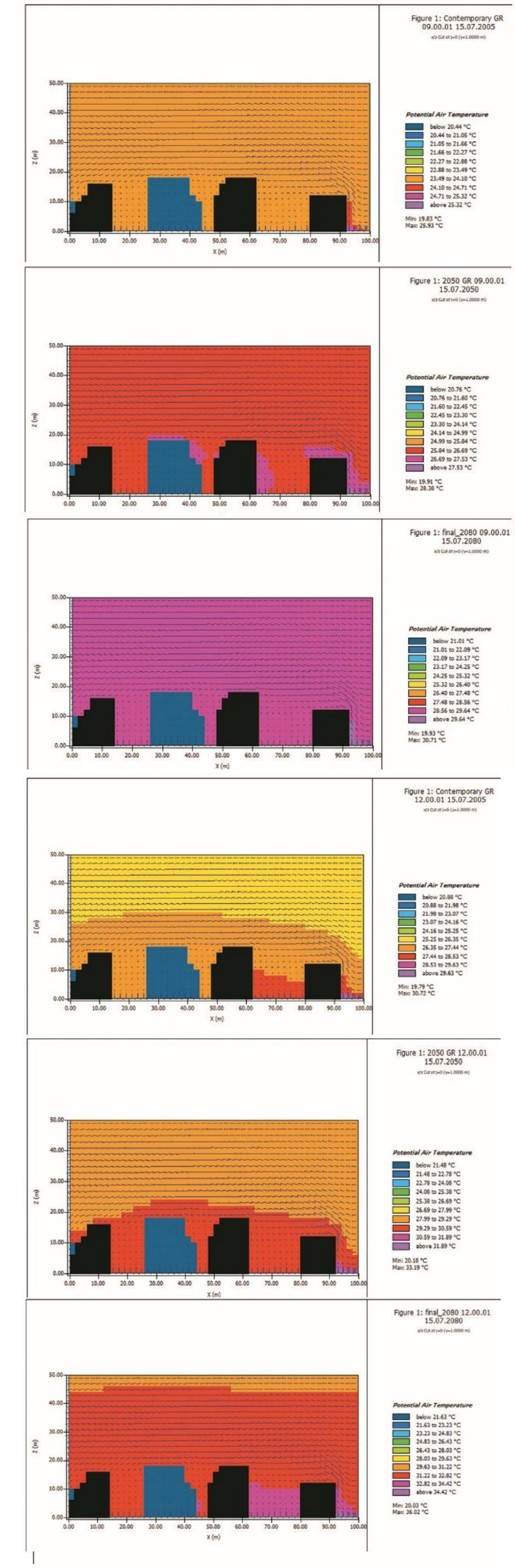

Figure 12: Temperature section, Greenhouse effect in Venizelou (Athens, Greece)

the anticipated continuation of rising temperatures, the demand for microclimate-modifying components, such as green roofs, is expected to escalate. Consequently, it is critical to conduct urban planning studies to assess the impact of these changes on the climate and its surroundings.

4. CASE STUDIES

This research focuses on the use of green roofs as a means of mitigation. The case studies examine how these changes are being implemented in a specific climate and city. To provide a more clear approach, a real project involving a green roof on the Ministry of Economics and Finance building in Athens, Greece is chosen. The green roof, which covers 650m² and 1.4 hectares, was installed on the rooftop of a ten-story building. The project aimed to study the impact of the green roof on thermodynamics in hot Athens. The building was constructed to provide a research roof to study the thermal effects of green roofs in Athens. The objective was to create a portable green roof to investigate the impact of rooftop gardens on biodiversity and the local microclimate, with the challenges of resilience, mitigation, biodiversity, and environmental quality in mind.[7]

There was a case study conducted in Turkey, which has a similar climate to Greece. The study aimed to investigate how green roofs impact microclimates and outdoor thermal comfort. It was carried out on a university campus and focused on determining whether green roofs can create a comfortable environment. The researchers surveyed users and used ENVI_met modelling to evaluate the influence of various roof terrace flooring materials on thermal comfort. The study found that green roofs and vegetation can help reduce high temperatures and improve outdoor thermal comfort on hot summer days. ENVI_met was used to estimate the effect of roof terrace flooring material on human thermal comfort. It was discovered that variation in flooring material can improve the outdoor thermal environment, depending on building geometry and the presence of trees. The comparison between trees and grass showed that trees improve thermal perception in the summer.[8]

5. CONCLUSION

The aim of this study was to assess the impact of green roofs on the microclimate of Athens. To achieve this, a number of case studies were analysed in relation to the use of green roofs to combat urban heat islands (UHIs). The results of this study were encouraging and suggest that green roofs can be an effective solution. Further research is required to understand the necessary adaptations. The research indicates that the implementation of green roofs has a positive impact. This assertion is supported by observed changes in temperature, humidity levels, and wind speed between 2050 and 2080, which demonstrate the stabilization of temperatures compared to areas without vegetation cover. Although this study focused on rooftop alterations, it highlights the importance of wider building refurbishments, including walls and other architectural elements. The ultimate aim of this study was to demonstrate the impact of changes that can encourage the construction industry to reconsider its approach to resilience. It is hoped that the findings of this study will lead to further research and implementation of green roofs as a potential solution to combat urban heat islands.

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